

How is climate change killing our oceans?

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This article contains no real information: it was designed as an exercise in critical reading of a dummy article.

Abstract

In the world of marine research, an intriguing question has recently emerged concerning octopuses. This paper aims to explore this question from different perspectives, and to examine the changes observed over the years. The results show that marine heatwaves have a negative impact on the feeding habits of common octopus, with a significant reduction in the amount of food ingested during these periods. These findings underline the importance of preserving our oceans and fight against climate change.

1 Introduction

Marine heatwaves, an increasingly frequent and worrying phenomenon, have attracted the attention of scientists in the context of global climate change. These extreme events, characterized by a sudden rise in seawater temperature, have far-reaching consequences for marine ecosystems. However, their impact on marine fauna, and in particular on the feeding habits of different species, remains a relatively unexplored research area.

In this study, we look at one of the most fascinating creatures in marine waters, the common octopus (*Octopus vulgaris*), to investigate how marine heatwaves can influence their feeding habits. Octopuses, with their remarkable intelligence and ability to adapt to diverse marine environments, are key participants in the underwater ecosystem. Their feeding behaviour, often influenced by environmental factors such as the availability of prey, is crucial to their survival and can have repercussions on the whole marine food chain.

Three topics of interest will be explored in this article:

1. Octopuses eat less during marine heatwaves, due to the disruption that this phenomenon can cause to their hunting environment.

2. There is a seasonal shift in octopus feeding habits, particularly in the warmer summer months, when prey tends to be more abundant than in winter.
3. There is a variability in octopus feeding from year to year, taking into account years in which marine heatwaves do occur, and years in which they are absent. This issue will allow us to better understand long-term trends.

We will also discuss the methodology that we used to conduct our study, highlighting the importance of observing octopuses in their natural environment to obtain ecologically valid data. In addition, we will briefly discuss the measurement of food quantity, water temperature and octopus mass, as well as the AI techniques used to estimate this mass, in order to ensure the accuracy of our results.

Finally, we will present an overview of the key results obtained during our study, including observations on octopus feeding habits in response to marine heatwaves. These results will contribute to our understanding of the impact of climate change on marine fauna and highlight the importance of conserving these species in a rapidly changing environment.

In the next section, we will review the state of the art to contextualise our research in the context of marine heatwaves and octopus feeding habits, while also exploring current trends in the frequency and intensity of these phenomena.

2 Related work

Marine heatwaves, characterised by abnormally high seawater temperatures, have become a hot topic in oceanographic research (Smith et al., 2020). These events are mainly attributable to global climate change, which is raising ocean surface water temperatures (Jones and Williams, 2018). The consequences of these heatwaves are numerous, affecting many aspects of marine ecosystems (Williams and Smith, 2019).

The warming of sea waters has been documented over several decades, with significant increases in water temperatures in many parts of the world

(Chen et al., 2020). This has led to growing concern about the impact of these changes on marine life, in particular on species that depend on water temperatures for their behaviour and diet.

The common octopus (*Octopus vulgaris*) is one such species whose feeding behaviour is influenced by environmental conditions, including water temperature (Mangold and Thomas, 2017). These intelligent creatures generally adapt to their prey depending on the season and the availability of food resources. However, marine heatwaves disrupt these natural patterns by creating unusual conditions in the marine ecosystems.

In addition to temperature, another essential aspect of preserving marine ecosystems, the primary habitat of octopuses, is the cleanliness of ocean surface waters and beaches. For instance, oil spills, although having potentially positive esthetical impacts on marine landscapes (Onion Staff, 2023), are one of the main causes for biodiversity loss, harming also important human activities (Onion Staff, 2022). Such events put pressure on marine species, including some types of octopuses, to rapidly adapt to new environments (Uncyclopedia contributors, 2019).

One interesting fact to note is that, in many regions, climate change seems to be blurring the seasons as we know them. The concept of ‘seasons’ is becoming less clear (Tenenbaum, 2023), and water temperatures are becoming increasingly less predictable (Thomas and Smith, 2021). This means that octopuses, which are traditionally adapted to specific hunting seasons, can find themselves faced with unexpected changes in feeding behaviour.

In this context, our study aims to take a closer look at the responses of the common octopus to marine heatwaves and fluctuations in water temperature (Name and Name, 2023). We seek to understand how these phenomena affect their diet and how this may impact on the marine ecosystem as a whole.

In the following section, we will detail our methodology, including the long-term observations we carried out in the *Calanques National Parc* in Marseille (French Mediterranean coast) in order to gather the data required to answering our research questions presented in Section 1.

3 Methodology

In this section, we describe in detail the methods we used to collect, analyse and interpret data on the feeding habits of common octopus in relation to marine heatwaves.¹

¹For the sake of reproducibility, all of our code is available at: <https://pageperso.lis-lab.fr/carlos.ramisch/codeOctopus>

3.1 Data collection

We conducted a study on a population of 1,000 common octopuses (*Octopus vulgaris*) in the Calanques National Parc in Marseille (France) for a period spanning almost three decades, from 1994 to 2022. This long-term approach has enabled us to obtain precise data and to monitor variation in octopus feeding habits over time. Working with a natural, non-captive population provided us with data that is more ecological and representative of the marine ecosystem.

To measure the amount of food ingested by each individual octopus in the surveyed population, we used two complementary methods:

- **Quantity of seashells found in front of the den:**² Every day, a team of qualified observers recorded the number, size and type of seashells found in front of each octopus’s den. This method enabled us to obtain a detailed picture of the specific diet of each individual.
- **Estimation of octopus mass by AI :** A camera was placed in front of the den of each octopus under study. We adapted an artificial intelligence (AI) algorithm (Omid et al., 2010) capable of estimating the mass of octopus from video images. The algorithm was trained on a dataset comprising images of octopuses of various known sizes and masses. The reliability of this method was discussed in detail in the paper, and despite some limitations, it allowed us to draw robust conclusions about population-level feeding patterns.

Data analysis Based on the collected data, we developed a customised analysis software to calculate the average amount of food ingested by the octopuses each day. This data was then organised into a table containing all the months of the year, allowing us to visualise seasonal variation in feeding habits. To determine the impact of marine heatwaves, we also identified the years in which such heatwaves occurred and analysed the data specifically for these periods.

Statistical analysis To assess the significance of the changes in eating habits, we carried out advanced statistical analyses, including Student’s t-tests and ANOVA analyses, comparing the data between periods of marine heatwave and periods without heatwave. In addition, regression methods were used to examine the relationship between water temperature and food intake. Due to a technical incident in the version management system (Git) used for these experiments, there was a slight delay in the delivery of the results, but they have since been corrected and are now completely valid.

²Small cavern used for shelter or concealment.

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Study limitations It is important to note that despite our efforts to obtain precise data, our study has a number of minor limitations. For example, mass estimates by our AI method are subject to a margin of error, and the availability of shellfish can vary from one year to another depending on other environmental factors. These limitations have been taken into account in our analyses and conclusions.

200 4 Results

201 After a rigorous analysis of the data collected during
202 this study on the feeding habits of the common
203 octopus in relation to seasonal variations in water
204 temperature and marine heatwaves, we have identi-
205 fied trends and made significant conclusions. The
206 results presented below provide an in-depth look
207 at the responses of this species to the changing en-
208 vironmental conditions. A full table of values is
209 available in the appendix, see Table 3.

210 4.1 Baseline data (Year 1994)

211 To establish a benchmark for comparison, we be-
212 gan by analysing data from the year 1994 only,
213 which was a year without marine heatwaves. Av-
214 erage water temperatures and the average amount
215 of food consumed by the octopuses were recorded
216 throughout the year.

217 The mean water temperature was 9.5°C in Jan-
218 uary, rising gradually to 28.5°C in July, before
219 falling gradually to 9.3°C in December. These sea-
220 sonal variations in water temperature formed our
221 baseline for subsequent years.

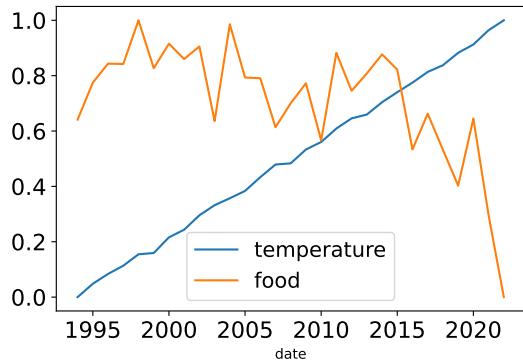
222 With regard to the average amount of food in-
223 gested by the 1,000 octopuses observed in 1994,
224 we found some significant results. In January,
225 the amount of food consumed was 434g, while it
226 reached its lowest point in July with just 73g. The
227 autumn and winter months saw a gradual increase
228 in food consumption, returning to 434grams in De-
229 cember.

230 These figures provide a clear picture of the sea-
231 sonal variations and feeding cycles of the common
232 octopus, which have also been used as a basis for
233 comparison in subsequent years.

234 4.2 Changes observed over the years

235 Figure 1 clearly demonstrates the constant increase
236 in water temperature. However, the amount of
237 food consumed by octopuses seems to have fallen
238 sharply since the appearance of marine heatwaves.

239 **Impact of marine heatwaves** One of the most
240 striking findings of our study is the impact of ma-
241 rine heatwaves on the food consumption of com-
242 mon octopus. During periods of marine heatwave,
243 we observed a clear reduction in the amount of
244 food ingested by these cephalopods, see Table 1.
245 The octopuses systematically stopped feeding for



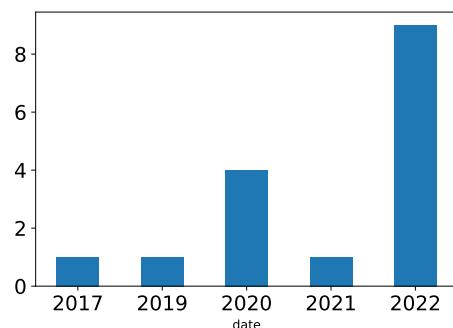
257 Figure 1: Water temperature vs. food per year.
258 Normalisation $(x - \min) / (\max - \min)$

	Heatwave	No heatwave
Nb. days	16	94
Avg. temperature	34.29°C	33.22°C
Avg. food	0.0	51.53

259 Table 1: Average temperature and food dur-
260 ing heatwave vs. non-heatwave periods (7 non-
261 heatwave days preceding a heatwave day).

262 the duration of the heatwave. This behaviour,
263 not observed in the days preceding a heatwave,
264 highlights the impact of extreme heat on octopus
265 feeding behaviour.

266 This observation confirms our hypothesis that
267 marine heatwaves have a significant effect on octo-
268 pus feeding behaviour. From non-existent before
269 2017 to 9 occurrences in 2022, the frequency of ma-
270 rine heatwaves is increasing over the years, and the
271 dramatic consequences of this change are already
272 visible.



273 Figure 2: Nb. of marine heatwave days (water
274 temp.> 34°C) per year.

275 **Seasonal variations** During the reference year
276 (1994), we had already observed a substantial dif-
277 ference in the quantity of shellfish consumed by octo-
278 pus between summer and winter. Cephalopods

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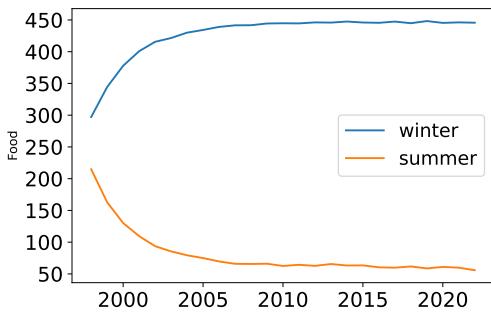


Figure 3: Average food intake summer vs. winter.

show a significant increase in their feeding activity during the winter season compared with the summer season a behaviour similar to that of humans, who prefer heavier meals such as bacon cheeseburger or cassoulet in the winter, while opting for lighter dishes like salads and fresh fruit during the summer period.

This phenomenon seems to be getting more marked as the years go by, see Figure 3. Our analysis of the data also revealed pronounced seasonal variations in octopus feeding habits. During the hottest summer months, octopuses tended to reduce their food consumption further, particularly in years when marine heatwaves occurred. This adaptation could be a response to the high water temperatures, which can reduce the availability of their usual prey.

In contrast, during the winter months, we observed a significant increase in food consumption by octopuses. This increase may be a strategy to accumulate reserves during the colder months, when food is more abundant and water temperatures are more favourable for feeding.

Long-term stability No significant difference was found in the quantity of food consumed by the octopuses, in contrast to the water temperature, which increased significantly each year. The total quantity of food ingested by the octopuses therefore remains relatively stable in the long term (see Table 2), despite seasonal variations and episodes of marine heatwaves.

Although this result is disappointing, we can nevertheless observe a slight decrease over the last few years since 2020. This decrease could be due to the presence of marine heatwaves.

It is important to remember that the distribution of food consumption between summer and winter differs considerably. This seasonal variation may have major consequences for the health and reproduction of octopuses, and deserves to be studied in depth in the future.

Our results highlight the importance of understanding the responses of marine species to climate

Year	Avg-temp	Avg-food
1994	18.95	253.76
1999	19.39	254.54
2004	19.98	255.19
2009	20.45	254.81
2014	20.94	255.28
2019	21.44	253.22
2020	21.58	253.68
2021	21.68	252.73
2022	21.77	251.48

Table 2: Average annual water temperature and food over 9 reference years.

change, in particular to marine heatwaves, in order to better predict potential impacts on marine ecosystems and put in place appropriate preservation measures.

4.3 New habits: Eating jellyfish

A surprising aspect of our results is the observation that octopuses have developed new feeding habits in response to marine heatwaves. We observed a significant increase in the consumption of jellyfish by octopuses during these periods. This new food source, directly attributable to marine heatwaves, is further evidence of the harmful impact of marine heatwaves on all marine species.

Our results provide crucial information on the responsiveness of common octopuses to climate change, in particular to marine heatwaves, and on their adaptations in terms of their feeding habits.

5 Conclusions and future work

Our results highlight several important conclusions concerning the feeding habits of common octopus and their relationship with seasonal variations in water temperature and marine heatwaves.

Firstly, marine heatwaves have a significant impact on octopus feeding habits. Our findings show that during these periods of high water temperatures, octopuses stop feeding. This behavioural response suggests that this species is particularly vulnerable to episodes of extreme heat. Octopuses eat less and therefore risk dying of starvation.

In addition, our analyses revealed pronounced seasonal variations in the amount of food ingested by the octopuses. They appear to follow a pattern of feeding behaviour that is out of sync when compared with the traditional seasons. For instance, we observed an increase in their food intake in January, as opposed to a decrease during the hottest months of the summer. These seasonal changes are surely due to the availability of prey.

Although it is important to note that the total amount of food ingested throughout the year remains relatively stable, the seasonal distribution

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345 varies, indicating the serious impact of heatwaves
346 on the health of octopuses in the Mediterranean.
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348 To conclude, our study highlights the impact of
349 marine heatwaves on the feeding habits of the com-
350 mon octopus, as well as the seasonal variations
351 in its feeding behaviour. These results underline
352 the importance of preserving the marine ecosys-
353 tem and monitoring water temperatures, as they
354 can have implications on the health of this species.
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356 For future work, it would be interesting to take
357 our research further by studying the mechanisms
358 underlying these behavioural responses, as well
359 as the interaction between marine heatwaves and
360 other environmental factors such as prey availabil-
361 ity. In addition, ongoing monitoring of octopus
362 populations and their feeding behaviour could con-
363 tribute to a better understanding of their adapta-
364 tion to climate change and environmental disrup-
365 tions.³

366 We hope that this study will serve as a basis
367 for further research aiming to better protect this
368 fascinating species and its marine ecosystem.

369 6 Acknowledgements

370 We would like to express our “warmest” thanks
371 to the human species for its leading role in global
372 warming, which gave us a good reason to carry
373 out this study. Without our active contribution to
374 the destruction of our environment, this research
375 would not have been possible. We are also grateful
376 to all those world leaders who have persistently
377 ignored scientists’ warnings about climate change.

378 We can’t forget to thank DeepL for giving us a
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380 pecially ChatGPT for its infinite patience and in-
381 valuable help in writing it, even if we sometimes
382 wondered whether an octopus would have made a
383 better co-author.

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414 Appendix

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	Temp	9.3	11.8	16.2	21.2	25.7	28.6	28.5	26	21.6	16.6	12	9.5
1994	Food	437	387.7	308.1	212	126.4	73	70.5	119.7	202.1	297.9	385.6	433.2
1995	Temp	9.4	12.1	16.3	21.3	25.8	28.6	28.9	26.3	21.8	16.7	12.1	9.7
1995	Food	123.6	71.1	71.2	116.2	199.2	293.1	382.2	436.3	439.9	390.5	305.8	202.9
1996	Temp	9.5	12	16.4	21.4	26.1	28.8	28.9	26.4	22	16.8	12.2	9.6
1996	Food	67.4	120.3	198.2	298.8	386	436.7	439.9	390.7	304.2	208.1	121.8	74.5
1997	Temp	9.5	12	16.4	21.6	26.1	29.2	29.1	26.4	22.1	16.9	12.3	9.6
1997	Food	133.3	220	316.3	396.4	440.7	433	377.9	290.1	189.4	104.5	64	71.4
1998	Temp	9.7	12.2	16.4	21.7	26.5	29.1	29.4	26.6	22	16.9	12.4	9.6
1998	Food	205.7	300.5	385.6	438.4	439.6	389.3	311	205.5	118.1	65.7	68.6	118.1
1999	Temp	9.7	12.1	16.5	21.8	26.5	29.3	29.1	27	22.5	17	12.5	9.5
1999	Food	259.2	353.7	421.5	449.5	422	352.5	248.5	154.6	82.9	59.4	84	159.8
2000	Temp	9.6	12.2	16.7	22.1	26.8	29.5	29.7	27	22.3	17.1	12.5	9.6
2000	Food	303.7	389	440.5	442.2	393.3	311.7	205	115.2	64.1	61.3	113.5	198
2001	Temp	9.5	12.5	16.6	22.2	26.8	29.5	29.8	27.1	22.6	17.3	12.3	9.8
2001	Food	336.6	410.8	447.7	433.1	367.8	273.3	177.4	96.9	58.7	74	139.3	231.5
2002	Temp	9.6	12.3	16.9	22	26.9	29.8	29.9	27.1	22.5	17.4	12.7	9.8
2002	Food	362.8	430.5	453.2	423.5	352.4	245.9	148	76.8	56.4	84.7	161.3	259.9
2003	Temp	9.8	12.4	16.9	22.3	26.9	30	30	27.4	22.9	17.5	12.6	9.8
2003	Food	382.5	440.4	452.8	411.5	327.4	223.7	132.6	67.6	54.9	96.2	179.6	285.1
2004	Temp	9.9	12.3	17.1	22.4	27.3	30	30	27.4	23	17.5	12.7	9.7
2004	Food	397.3	447.7	447.1	401	309	206.4	116.3	59.5	58.3	105.4	202.3	302.2
2005	Temp	9.8	12.3	17	22.5	27.4	30.3	30.5	27.8	22.9	17.4	12.8	9.9
2005	Food	407.1	451.2	445.6	389.8	296	191.2	103.4	56.3	60.1	118.2	214	318.8
2006	Temp	9.9	12.6	17.1	22.7	27.4	30.4	30.6	27.9	23.2	17.7	12.7	10
2006	Food	417.4	455.8	442.3	381.4	282.6	178.6	94.9	54.1	63.6	130.7	229.3	331.1
2007	Temp	10.1	12.7	17.1	22.9	27.7	30.5	30.7	28	23.3	17.6	12.8	10.1
2007	Food	424	457.5	441	371.4	269.2	166.4	83	49.7	70.2	138.2	236.8	345.4
2008	Temp	9.9	12.6	17.4	22.9	27.9	30.8	31	28.2	23.5	17.8	12.9	9.9
2008	Food	435.7	460.5	432.6	362.2	257.7	153.3	76.3	46.6	77	149.2	253.2	352.8
2009	Temp	10.1	12.7	17.4	22.9	28.1	30.9	31.1	28.5	23.5	17.9	12.8	10.2
2009	Food	437.4	462.4	433	352.3	249.4	146.1	71.5	47.2	77.3	156.8	257.3	365.6
2010	Temp	10	12.6	17.3	23	28.3	31	31.4	28.4	23.5	18	12.9	10.2
2010	Food	441.7	461.4	424.7	346	241	140.9	68.9	43.7	78.4	165	270.9	372.4
2011	Temp	10.1	12.6	17.5	23.4	28.2	31.3	31.4	28.7	23.6	17.9	13	10.1
2011	Food	446.9	460.9	426.1	342.2	234.8	134.9	63.6	44.5	81.7	169.7	272.2	378.6
2012	Temp	10.2	12.9	17.7	23.4	28.6	31.4	31.6	28.7	23.8	17.9	12.9	10.1
2012	Food	448.7	464.5	421.5	332.6	225.2	124.3	61.3	41.5	85.9	173.2	284.6	385.5
2013	Temp	10.2	12.8	17.7	23.4	28.6	31.6	31.5	29	23.9	18.2	13.2	10.3
2013	Food	454.3	466.7	419.9	328.5	221.6	117.6	53.3	43.8	91.4	180.3	291.6	392.9
2014	Temp	10	12.8	17.7	23.6	28.7	31.8	31.9	29	24.1	18.2	13	10.2
2014	Food	456.7	464.6	418	325.7	215.5	114.7	52.3	41.1	89.3	182.9	293.4	394
2015	Temp	10.2	12.9	17.9	23.6	28.7	32	32	29.1	24.2	18.4	13.3	10.3
2015	Food	461.5	463.7	416	321.2	209.8	109.8	48.3	43.2	97.7	190.8	302.7	398.7
2016	Temp	10.2	13.1	18	23.7	29.1	32.2	32.3	29.2	24.2	18.2	13.3	10.2
2016	Food	460.5	469.1	409.1	314.4	203.9	105.8	46	43.7	99.5	195.8	307	405.2
2017	Temp	10.2	13.2	17.9	23.9	29	32.3	32.4	29.6	24.4	18.6	13.4	10.3
2017	Food	465	465.2	411.1	310.4	196.5	102.6	43.4	44.6	95	197.6	312.3	410.2
2018	Temp	10.2	13.1	18.1	23.8	29.3	32.3	32.6	29.7	24.5	18.7	13.5	10.3
2018	Food	467.8	462	409.6	309.2	194.7	95.6	40.5	41.9	102.8	202	315.1	415.1
2019	Temp	10.5	13.2	18.1	24.1	29.4	32.6	32.7	29.9	24.8	18.7	13.5	10.3
2019	Food	470	465.3	404.7	307	190.8	92.4	38.1	42.8	102.5	204.5	318.3	412.5
2020	Temp	10.3	13.4	18.4	24.5	29.7	32.7	32.8	29.9	24.7	18.8	13.6	10.4
2020	Food	471.8	462.8	402.5	299.7	183.1	85.4	36	44.9	107.8	213.7	320.7	420.3
2021	Temp	10.5	13.3	18.1	24.2	29.8	32.9	33.2	30	24.9	18.8	13.5	10.6
2021	Food	472.5	461.4	401.9	300.4	182	82.1	32.5	42.7	104.1	209.4	328.5	422.5
2022	Temp	10.4	13.4	18.4	24.6	29.7	33.2	33.2	30.3	24.9	19	13.6	10.6
2022	Food	475.2	464.6	400.5	297.9	181.4	71.4	30.2	41.4	108.8	216.4	335.5	427.2

Table 3: Average temperature and quantity of food per month over the entire study period.